

Age profile of susceptibility, mixing, and social distancing shape the dynamics of the novel coronavirus disease 2019 outbreak in China

Supplementary Materials

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1. Timeline of contact surveys and interventions in Wuhan and Shanghai

We conducted two social contact surveys from February 1, 2020 to February 10, 2020, as the novel coronavirus 2019 outbreak (COVID-19) was starting to spread widely across China. At that time several control strategies were implemented. A timeline of the main events in Wuhan and Shanghai is shown in Fig. S1 and S2. Wuhan was put on lock down on January 23, 2020, with most of its commercial activity suspended until March 10, 2020. Close community management and social distancing were gradually introduced starting on January 28, 2020 (e.g. only one household member was allowed to purchase supplies every three days). In Shanghai, as in other provinces outside Hubei, private firms had to stop operations from January 28, 2020 to February 9, 2020, and close community management was put in place. In both locations additional restrictions were put in place, including extension of the traditional Chinese New Year holidays until February 2, 2020, suspension of group tours, closure of public cultural institutions (e.g., libraries, museums), and postponement of the spring semester for schools of all levels (1-3). The main control measures implemented in Wuhan and Shanghai are summarized in Fig S1-2 and Tab. S1.

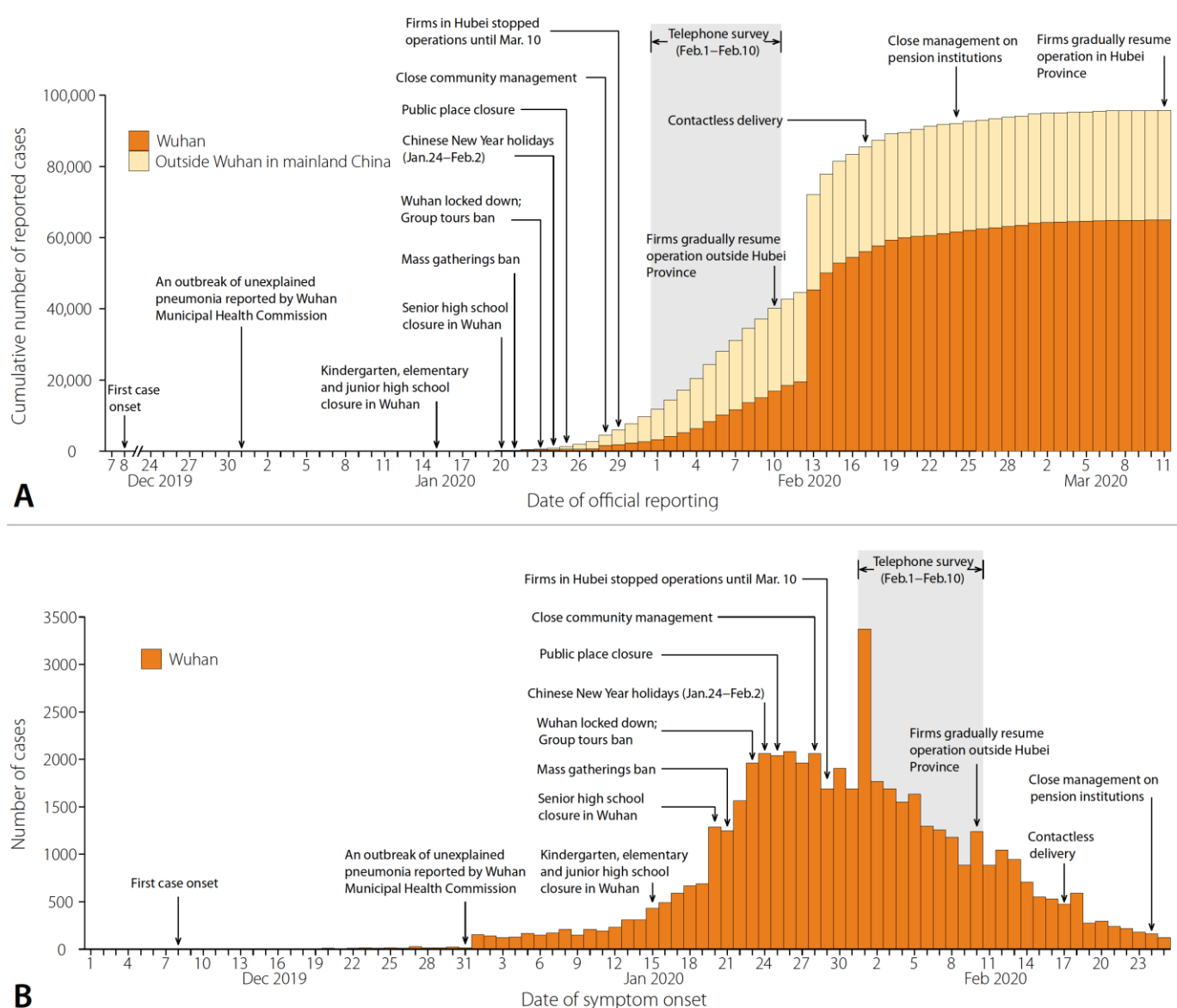


Figure S1. A Cumulative number of reported cases in Wuhan, timeline of key events, and timeline of the survey. **B** Same as A, but showing the epidemic curve (i.e., the daily number of cases by date of symptom onset).

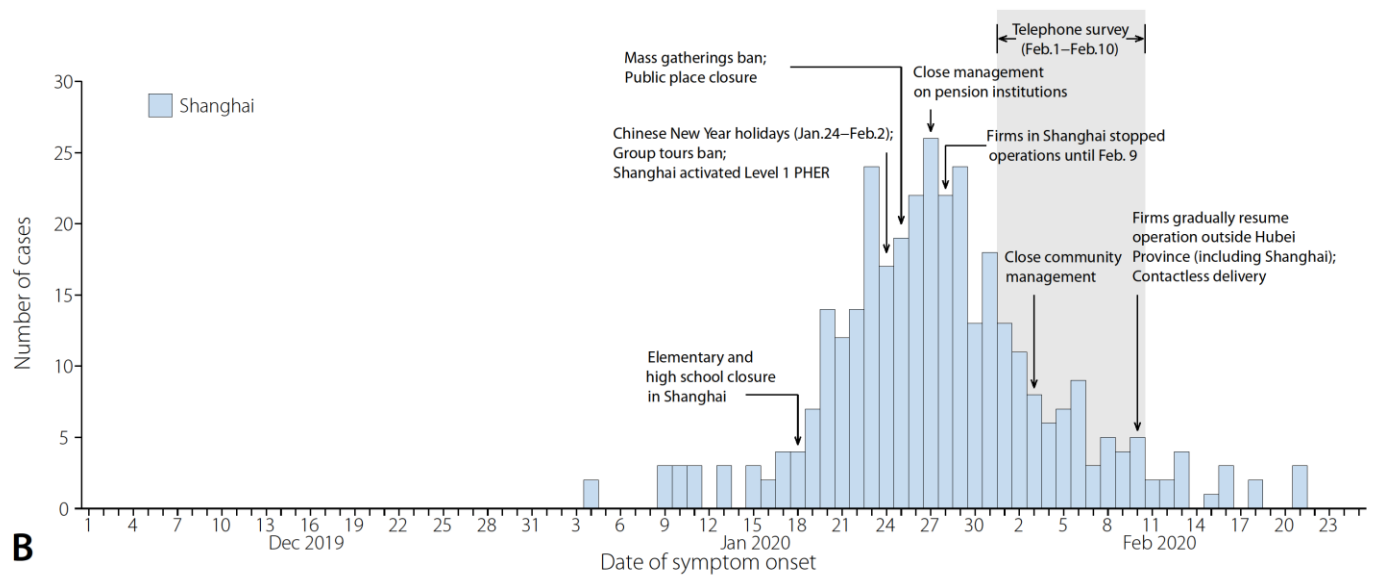
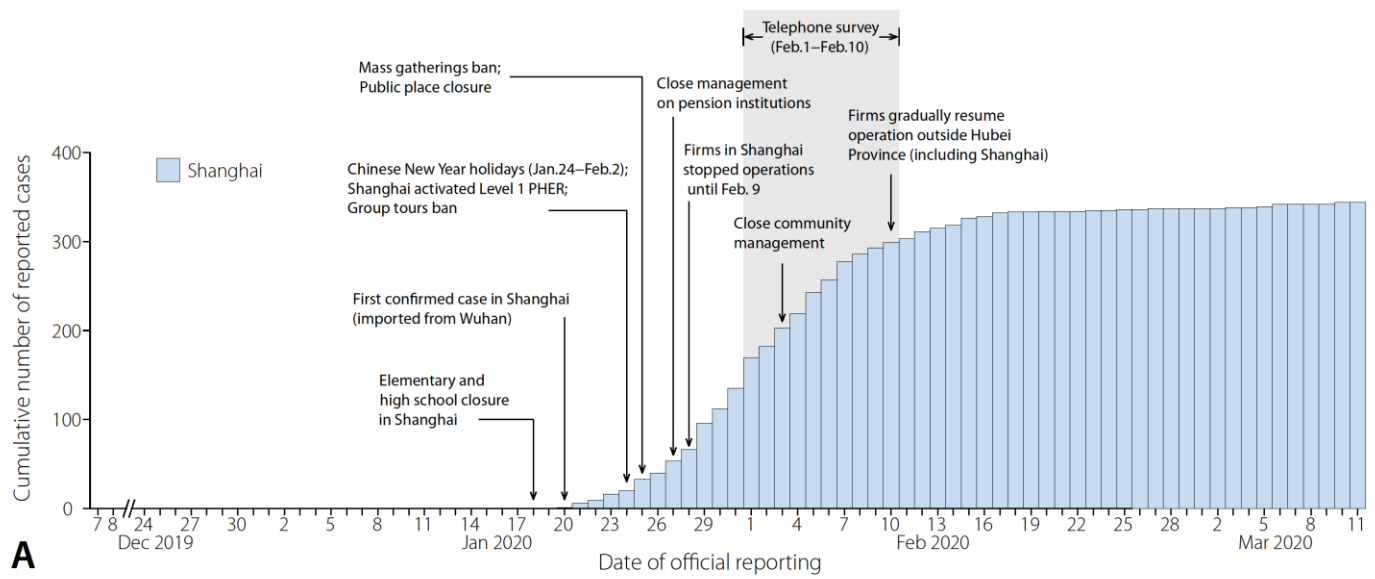


Figure S2. A Cumulative number of reported cases in Shanghai, timeline of key events, and timeline of the survey. **B** Same as A, but showing the epidemic curve (i.e., the daily number of cases by date of symptom onset)

Table S1. Main control measures implemented in Wuhan and Shanghai.

Location	Type	Target population	Subtype	Intervention	Start date	End date	Source
Wuhan							
	Case isolation and close contact management	confirmed cases	isolation	designated hospitals for cases	2020/1/20		http://wjw.wuhan.gov.cn/front/web/showDetail/2020012009078
	Case isolation and close contact management	suspected cases	isolation	centralized isolation on suspected cases	2020/2/2		http://www.wuhan.gov.cn/2019-web/whyw/202002/t20200203_304370.html
	Case isolation and close contact management	close contacts	isolation	centralized isolation on close contacts	2020/2/2		http://www.wuhan.gov.cn/2019-web/whyw/202002/t20200203_304370.html
	Case isolation and close contact management	fever patients	isolation	centralized isolation on patients with fever	2020/2/2		http://www.wuhan.gov.cn/2019-web/whyw/202002/t20200203_304370.html
	Case isolation and close contact management	cured cases	isolation	isolation on recovered patients	2020/2/22		https://www.thepaper.cn/newsDetail_forward_6088503
	Environmental/general sanitation	general population	disinfection	disinfection on public transportation	2020/1/7		www.wuhan.gov.cn/2019-web/whyw/202001/t20200123_304125.html
	Environmental/general sanitation	general population	disinfection	disinfection in public places	2020/1/22		http://wh.bendibao.com/live/2020121/106813.shtml
	Environmental/general sanitation	general population	disinfection	disinfection in the whole city	2020/2/9		http://www.wuhan.gov.cn/2019-web/whyw/202002/t20200210_304586.html
	Environmental/general sanitation	general population	wear masks	wear masks in public places	2020/1/22		http://www.wuhan.gov.cn/2019-web/whyw/202001/t20200123_304073.html
	Increase interpersonal distance	general population	activity ban	close community management	2020/1/28-2020/2/11		http://www.bzdc.cn/bzms/65296.html
	Increase interpersonal distance	general population	activity ban	mass gatherings ban	2020/1/21		http://www.xinhuanet.com/2020-01/21/c_1125490833.htm
	Increase interpersonal distance	general population	activity ban	group tours ban	2020/1/23		http://www.hubei.gov.cn/zhuanti/2020/gzxxgzbd/zxtb/202001/t20200123_2014602.shtml
	Increase interpersonal distance	general population	activity ban	public place closure	2020/1/25		https://www.mct.gov.cn/whzx/whyw/202002/t20200204_850635.htm
	Increase interpersonal distance	general population	activity ban	contactless delivery	2020/2/17		http://www.wuhan.gov.cn/2019-web/whyw/202002/t20200218_305034.html
	Increase interpersonal distance	general population	activity ban	close management on pension institutions	2020/2/24		http://www.wuhan.gov.cn/2019-web/whyw/202002/t20200225_305500.html
	Increase interpersonal distance	general population	workplace closure	extension of the Spring Festival holiday	2020/2/1	2020/2/13	http://www.hubei.gov.cn/zhuanti/2020/gzxxgzbd/zxtb/202002/t20200201_2017564.shtml
	Increase interpersonal distance	general population	workplace closure	detention of enterprise re-work	2020/1/29	2020/3/10	http://www.hubei.gov.cn/zhuanti/2020/gzxxgzbd/zxtb/202002/t20200220_2143275.shtml
	Personnel quarantine	general population	temperature measurement	temperature measurement at public transportation	2020/1/15		www.wuhan.gov.cn/2019-web/whyw/202001/t20200123_304125.html
	Personnel quarantine	general population	temperature measurement	temperature measurement at public places	2020/1/29		http://www.wh.gov.cn/hbgovinfo/zwgk_8265/tzgg/202001/t20200130_304277.html

Personnel quarantine	general population	cross-examination	first-round cross-examination on all residents	2020/1/24	2020/2/10	http://www.hubei.gov.cn/zhuanti/2020/xgfyqfkzszq/fwzq/zclxx/202001/t20200124_2014779.shtml
Personnel quarantine	general population	cross-examination	second-round cross-examination on all residents	2020/2/17	2020/2/19	http://www.wuhan.gov.cn/2019web/whyw/202002/t20200211_304661.html
Personnel quarantine	general population	cross-examination	health surveillance on all residents	2020/2/7		http://www.wh.gov.cn/2019web/whyw/202002/t20200220_305176.html
Traffic restrictions	general population	inter-province/city travel ban	city lockdown	2020/1/23		http://www.wuhan.gov.cn/hbgovinfo/zwgk_8265/tzgg/202001/t20200123_304065.html
Traffic restrictions	general population	inner-province/city travel limitation	taxi limitation	2020/1/24		https://baijiahao.baidu.com/s?id=1656567890994404313&wfr=spider&for=pc
Traffic restrictions	general population	inner-province/city travel limitation	partial road closure	2020/1/25		http://www.wuhan.gov.cn/2019web/whyw/202001/t20200125_304153.html
Traffic restrictions	general population	inner-province/city travel ban	motor vehicle ban	2020/1/26		http://www.wuhan.gov.cn/2019web/whyw/202001/t20200127_304182.html
Personnel quarantine	returnees	cross-examination	health surveillance on returnees	2020/1/31		http://www.wh.gov.cn/hbgovinfo/zwgk_8265/tzgg/202002/t202001_304332.html
Personnel quarantine	population with fever	cross-examination	health surveillance on population with fever	2020/2/17		http://www.hubei.gov.cn/zhuanti/2020/gzxxgzbd/zxtb/202002/t20200218_2096672.shtml
Other restrictions	wild animal	—	wild animal market closure	2020/1/29		http://www.wh.gov.cn/hbgovinfo/zwgk_8265/tzgg/202001/t20200130_304277.html
Other restrictions	wild animal	—	live poultry market closure	2020/1/29		http://www.wh.gov.cn/hbgovinfo/zwgk_8265/tzgg/202001/t20200130_304277.html
Other restrictions	population with fever	—	registration when buying medicine	2020/1/30		http://www.wh.gov.cn/hbgovinfo/zwgk_8265/tzgg/202001/t20200130_304278.html

Shanghai

Case isolation and close contact management	confirmed cases	isolation	designated hospitals for cases	2020/1/21		http://news.cngold.org/gundong/2020-01-22/c6824823.html
Case isolation and close contact management	close contacts and fever patients	isolation	centralized isolation on close contacts and fever patients	2020/1/21		http://news.sina.com.cn/bn/society/2020-01-21/detail-iihnzhha4003623.d.html
Case isolation and close contact management	people from severe epidemic areas	isolation	isolation on people from severe epidemic areas	2020/1/24		http://wsjkw.sh.gov.cn/xwfb/20200126/bf3a84555c1b4bde839e56db7e610cbc.html
Environmental/general sanitation	general population	disinfection	disinfection on public transportation	2020/1/22		http://sh.people.com.cn/n2/2020/0122/c176737-33739894.html
Environmental/general sanitation	general population	disinfection	disinfection in public places	2020/1/22		https://new.qq.com/omn/20200130/20200130A04WA700.html?pc
Environmental/general sanitation	general population	wear masks	wear masks in public transportation	2020/2/5		https://m.weibo.cn/status/4468666932004021
Environmental/general sanitation	general population	wear masks	wear masks in public places	2020/2/8		https://baijiahao.baidu.com/s?id=1657964155677045855&wfr=spider&for=pc
Increase interpersonal	general population	activity ban	group tours ban	2020/1/24		http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw4

distance							8539/u21aw1423565.html
Increase interpersonal distance	general population	activity ban	mass gatherings ban	2020/1/25			http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48539/u21aw1423526.html
Increase interpersonal distance	general population	activity ban	public place closure	2020/1/25			http://sh.sina.com.cn/news/m/2020-01-28/detail-iihnzhha5133716.shtml
Increase interpersonal distance	general population	activity ban	contactless delivery	2020/1/27			http://www.shweilao.cn/cms/cmsDetail?uuiid=f72e75a2-687f-4db4-94ed-1db37c1e1b98
Increase interpersonal distance	general population	activity ban	close management on pension institutions	2020/1/27			https://web.shobserver.com/news/detail?id=219178
Increase interpersonal distance	general population	activity ban	close community management	2020/2/3-2020/2/8			https://baijiahao.baidu.com/s?id=1657956799138015813&wfr=spider&for=pc
Increase interpersonal distance	general population	workplace closure	extension of the Spring Festival holiday	2020/2/1	2020/2/2		http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48545/nw48635/u26aw63482.html
Increase interpersonal distance	general population	workplace closure	detention of enterprise re-work	2020/1/28	2020/2/9-2/28		http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48539/u21aw1423599.html
Personnel quarantine	general population	temperature measurement	temperature measurement at public transportation	2020/1/23			http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48539/u21aw1423542.html
Personnel quarantine	general population	temperature measurement	temperature measurement at public places	2020/2/8			http://m.gmw.cn/2020-02/08/content_1300927367.htm
Traffic restrictions	general population	from/ to Hubei travel ban	interprovincial bus travel from/ to Hubei ban	2020/1/23			http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48539/u21aw1423542.html
Traffic restrictions	general population	inter-province/city travel ban	interprovincial and interurban bus travel ban	2020/1/26	2020/2/20		http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48539/u21aw1423571.html
Other restrictions	population with fever	—	registration when buying medicine	2020/1/23			http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48539/u21aw1426132.html
Other restrictions	wild animal	—	wild animal market closure	2020/1/26			http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48545/nw48607/u26aw63618.html
Other restrictions	wild animal	—	live poultry market closure	2020/1/26			http://www.shanghai.gov.cn/nw2/nw2314/nw32419/nw48516/nw48545/nw48607/u26aw63618.html

2. Structure of the contact survey questionnaire

Questionnaires were administered by phone by trained staff; a summary of the sampling scheme is provided below. The questionnaire consisted of three sections: 1) general information (e.g., sex, age, type of profession, and household size); 2) contact diary for a regular weekday between December 24, 2020 and December 30, 2020 before the day when the outbreak of an unexplained pneumonia was officially announced by Wuhan Municipal Health Commission (used as baseline); and 3) contact diary during the COVID-19 outbreak. In line with the POLYMOD study(4), a contact was defined as either, (1) a two-way conversation with three or more words in the physical presence of another person (conversational contact), or (2) direct physical contact (e.g., a handshake, hug, kiss or performing contact sports). For the contact diary during the outbreak, participants were requested to record each contact they had within a 24 hour period from 5:00am of the day before the telephone interview to 5:00am the day of the interview. For each contact, the following information was recorded: age, sex, relation, social setting where the contact took place (e.g., home, workplace), and type of contact (conversational or physical). For the contact diary related to regular days, contacts were aggregated by age group.

3. Survey sampling

The survey was conducted by using a platform well-established by the authors during the outbreak of human infection with avian influenza A(H7N9), which uses a computerized random digital dialing system(6). The sample size was calculated based on the same methodology used in our previous survey(5). We planned to recruit 500 adults in each location. To obtain an age-representative sample, we planned to recruit an additional 88 and 62 participants under 18 years in Wuhan and Shanghai, respectively. Accounting for 90% response rate, we targeted about 650 participants per study site. The effective number of participants was 636 in Wuhan and 557 in Shanghai. Eligibility criteria were defined as: 1) being a local resident of Shanghai or Wuhan of any age; 2) having lived in the selected city for more than six months in the past year; 3) being present in the city at the time of interview. Proportional quota sampling based on age and sex was used to ensure a demographically representative sample of the general population in each city. Calls were placed three times at different hours on the same day before being classified as invalid. Interviews of underaged individuals took place after the approval of the legal guardian who assisted the child in responding to the questionnaire. Who completed the questionnaire depended on the participant's age, 1) parental-proxy completion for 0 to 10; 2) completion by participant for 11 to 17 subject to parental informed consent; and 3) completion by participant for 18 or above. Fig. S3 shows the flow chart of the participant recruitment process.

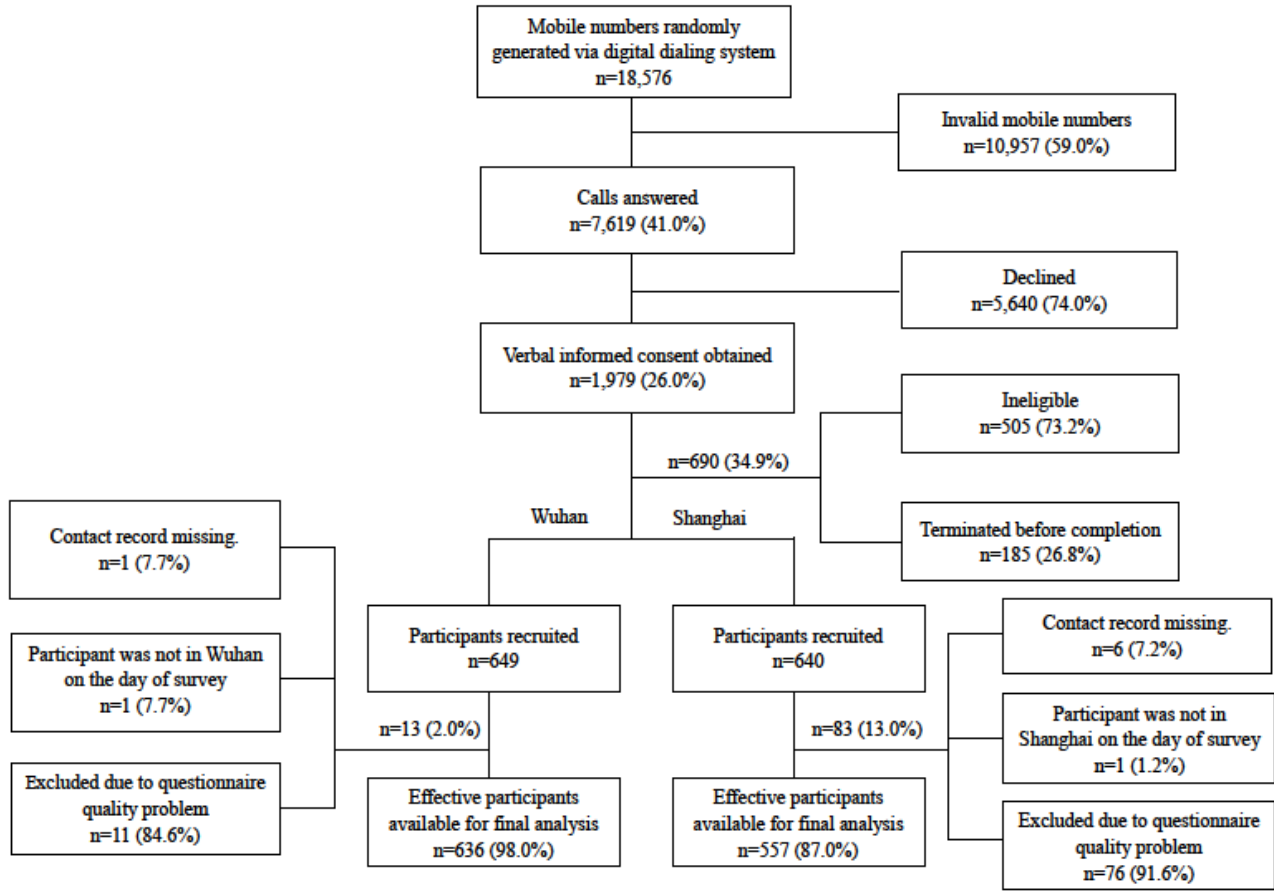


Figure S3. Flow chart of the sampling telephone survey.

4. Statistical analysis

We tested changes in mixing patterns in Wuhan using paired t-test and in Shanghai using the two-sample t-test. We used two-sample t-test to compare the two cities for a regular weekday period and the COVID-19 outbreak. We used generalized additive models (GAMs) to assess the effect of participant age and household size on the number of contacts. Penalized splines were used to explore potential nonlinear associations between continuous participant age and the number of contacts.

We defined 14 age groups (0-4 y, 5-9 y, 10-14 y, 15-19 y, 20-24 y, 25-29 y, 30-34 y, 35-39 y, 40-44 y, 45-49 y, 50-54 y, 55-59 y, 60-64 y, 65 y and over) to build age-specific contact matrices, aiming to estimate the age-specific contact rate per person per day, using the “socialmixr” package in R 3.6.0. Contact matrices representing a regular weekday (hereafter referred to as “regular day contact matrix”) and for the COVID-19 outbreak (hereafter referred to as “outbreak contact matrix”) were estimated for both Wuhan and Shanghai(5). We also built within-household contact matrices for COVID-19 and calculated the correlation between the household-specific and full contact matrices during the outbreak.

5. Ethics approval

Ethics approval was obtained from the institutional review board of the School of Public Health, Fudan University (IRB#2020-TYSQ-01-1). Verbal informed consent was obtained from all subjects (from a parent/guardian if participant was below 18 years of age).

6. Data representativeness

Overall, 1,193 participants (636 in Wuhan and 557 in Shanghai) were included in the analysis. In Wuhan, 329 (51.7%) of participants were female, the average age was 36 years (range 1-82), and the average household size was 3 (range 1-11). In Shanghai, 271 (48.7%) of participants were female, the average age was 37 years (range 1-85), and the average household size was 3 (range 1-8). We also included 543 individuals from our previous contact survey conducted during regular weekdays in Shanghai(5).

The demographics of enrolled participants in Wuhan and Shanghai aligned well with the actual populations of the two cities (Tab. S2-3, and Fig. S4), although in both locations we have a slight under sampling of individuals aged between 0 and 4 years and aged 65+ years.

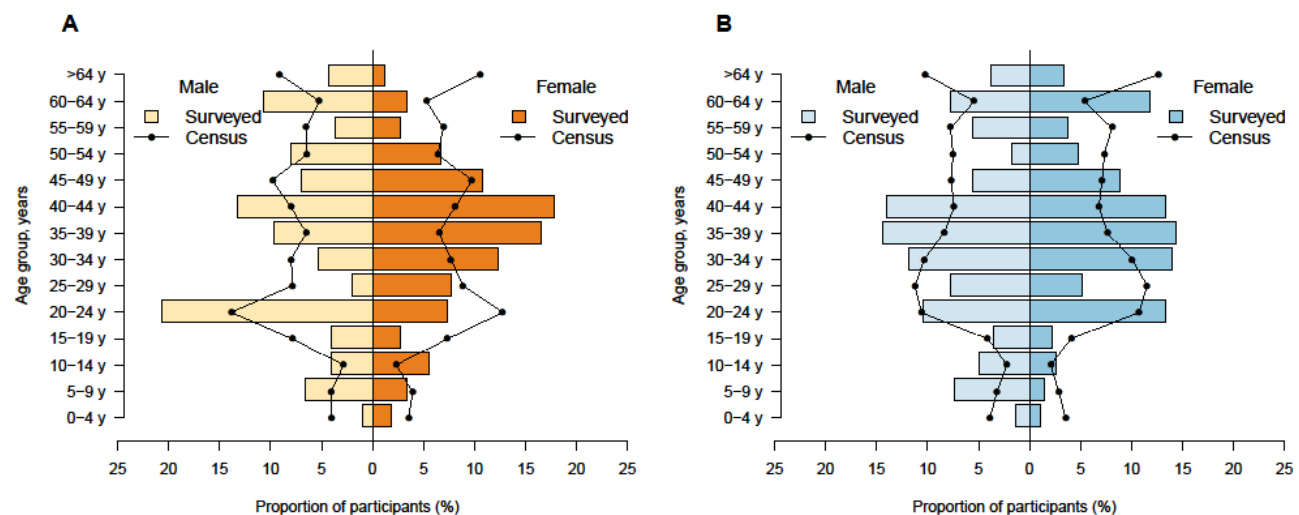


Figure S4. **A** Study population demographics by age and gender for Wuhan. **B** Same as A, but for Shanghai. Black dotted lines denote expected distributions based on age-gender distributions derived from census 2016.

Table S2. Comparison between the total population and contact survey participants in Wuhan.

Characteristics	Total population (%) (n= 9,785,388)	Effective participants (%) (n=636)
Sex		
Female	5,515,617 (51.23)	329 (51.73)
Male	5,250,583 (48.77)	307 (48.27)
Age group		
[0,10)	839,016 (7.79)	40 (6.29)
[10,20)	1,099,717 (10.21)	51 (8.02)
[20,30)	2,326,297 (21.61)	118 (18.55)
[30,40)	1,543,492 (14.34)	139 (21.86)
[40,50)	1,914,285 (17.78)	161 (25.31)

[50,60)	1,417,978 (13.17)	66 (10.38)
[60,70)	921,259 (8.56)	57 (8.96)
[70,100)	704,156 (6.54)	4 (0.63)

Table S3. Comparison between the total population and contact survey participants in Shanghai.

Characteristics	Total population (%) (n= 24,152,700)	Effective participants (%) (n=557)
Sex		
Female	12,594,652 (52.15)	271 (48.65)
Male	11,558,048 (47.85)	286 (51.35)
Age group		
[0,10)	1,637,542 (6.78)	32 (5.75)
[10,20)	1,521,592 (6.30)	37 (6.64)
[20,30)	5,313,513 (22.00)	102 (18.31)
[30,40)	4,396,951 (18.20)	152 (27.29)
[40,50)	3,509,511 (14.53)	116 (20.83)
[50,60)	3,708,013 (15.35)	44 (7.9)
[60,70)	2,137,007 (8.85)	69 (12.39)
[70,100)	1,928,571 (7.98)	5 (0.9)

7. Descriptive characteristics of contact patterns

Fig. S5 shows the average number of daily contacts (including physical contacts and conversational contacts) by 5-year age groups. We observed that at baseline, in the non-epidemic period, Shanghai residents have more contacts than Wuhan. In both cities, the average number of contacts per participant was significantly reduced during the COVID-19 outbreak and this was consistent across all age groups. During the outbreak, the number of contacts was similarly low in the two cities (2-3 contacts/day) and age differences disappeared. The distributions of contacts, including the median and interquartile ranges (IQR), are reported in Fig. S6 and Tab. S4. No significant gender difference was found in the contacts of any age group.

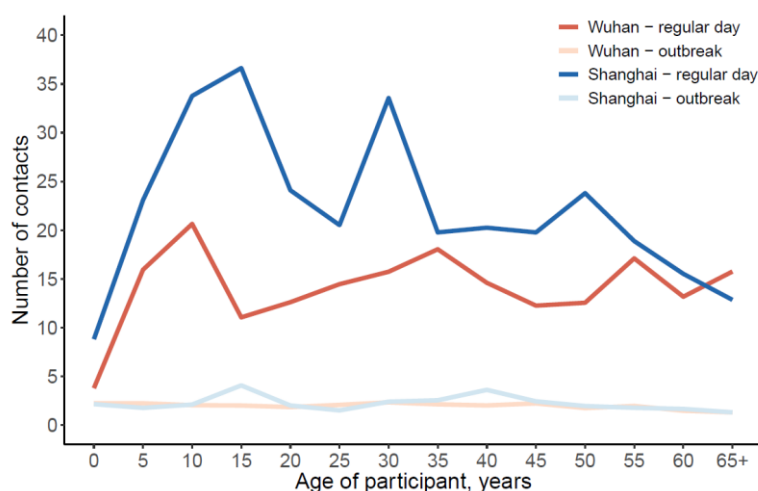


Figure S5. Average daily number of reported contacts in two large cities (Wuhan City and Shanghai City), by period (regular non-outbreak weekday, and weekday during the COVID-19 outbreak).

Table S4. Median number of reported contacts by respondent characteristics, city, and time period.

Characteristics	Wuhan				Shanghai			
	Regular day		COVID-19 Outbreak		Regular day		COVID-19 Outbreak	
	N (%) ^a	Median (IQR)	N (%) ^a	Median (IQR)	N (%)	Median (IQR)	N (%)	Median (IQR)
Overall	624 (100.0)	7 (3, 15)	627 (100.0)	2 (1, 2)	543	14 (5, 32)	557 (100.0)	2 (1, 3)
Sex								
Male	300 (48.1)	6 (2, 18)	301 (48)	2 (1, 2)	264 (48.6)	14 (5, 33.3)	286 (51.3)	2 (1, 2.8)
Female	324 (51.9)	7.5 (3, 15)	326 (52)	2 (2, 2)	279 (51.4)	14 (4, 32)	271 (48.7)	2 (1, 3)
Age group								
0-6 y	12 (1.9)	4.5 (2, 6.5)	12 (1.9)	2 (2, 2)	51 (9.4)	4 (3, 20.5)	14 (2.5)	2 (2, 2)
7-19 y	79 (12.7)	9 (5, 23.5)	79 (12.6)	2 (2, 2)	83 (15.3)	34 (26, 42)	55 (9.9)	2 (2, 3)
20-39 y	254 (40.7)	7 (3, 19)	256 (40.8)	2 (1, 2.3)	132 (24.3)	19 (7, 36)	254 (45.6)	2 (1, 3)
40-59 y	221 (35.4)	6 (2, 13)	220 (35.1)	2 (1, 2)	126 (23.2)	14.5 (6, 27.8)	160 (28.7)	2 (1, 3)
>59 y	58 (9.3)	3.5 (1, 11.75)	60 (9.6)	1 (1, 2)	151 (27.8)	7 (3, 17)	74 (13.3)	1 (1, 2)
Type of profession								
Pre-school	12 (1.9)	4.5 (2, 6.5)	12 (1.9)	2 (2, 2)	43 (7.9)	4 (3, 11.5)	14 (2.5)	2 (2, 2)
Student	107 (17.1)	8 (3.5, 14)	107 (17.1)	2 (2, 2)	100 (18.4)	32 (22.8, 41)	71 (12.7)	2 (2, 3)
Employed	391 (62.7)	11 (6, 36)	390 (62.2)	2 (1.8, 3.8)	236 (43.5)	18.5 (7, 36)	354 (63.6)	2 (1, 3)
Unemployed	30 (4.8)	4 (2, 7.5)	31 (4.9)	2 (1, 2)	10 (1.8)	6 (3.3, 12.5)	24 (4.3)	2 (0.8, 3)
Retired	84 (13.5)	4 (1.8, 9.3)	87 (13.9)	1 (1, 2)	152 (28)	5.5 (3, 15)	94 (16.9)	1 (1, 2)
Household size								
1-2	118 (18.9)	5 (1, 11)	121 (19.3)	1 (0, 1)	166 (30.6)	8 (3, 21)	199 (35.7)	1 (0, 1)
3-4	415 (66.5)	7 (3, 15)	415 (66.2)	2 (2, 2)	306 (56.4)	17 (5, 34)	294 (52.8)	2 (2, 3)
>4	91 (14.6)	10 (4, 26)	91 (14.5)	3 (2, 4)	71 (13.1)	23 (6.5, 39.5)	64 (11.5)	4 (4, 4.3)

^aCan differ from total sample size (n=636) as it also includes participants who had not recorded contacts during regular weekdays or during the COVID-19 outbreak. Note that reduced denominators indicate missing data. Percentages may not total 100 because of rounding.

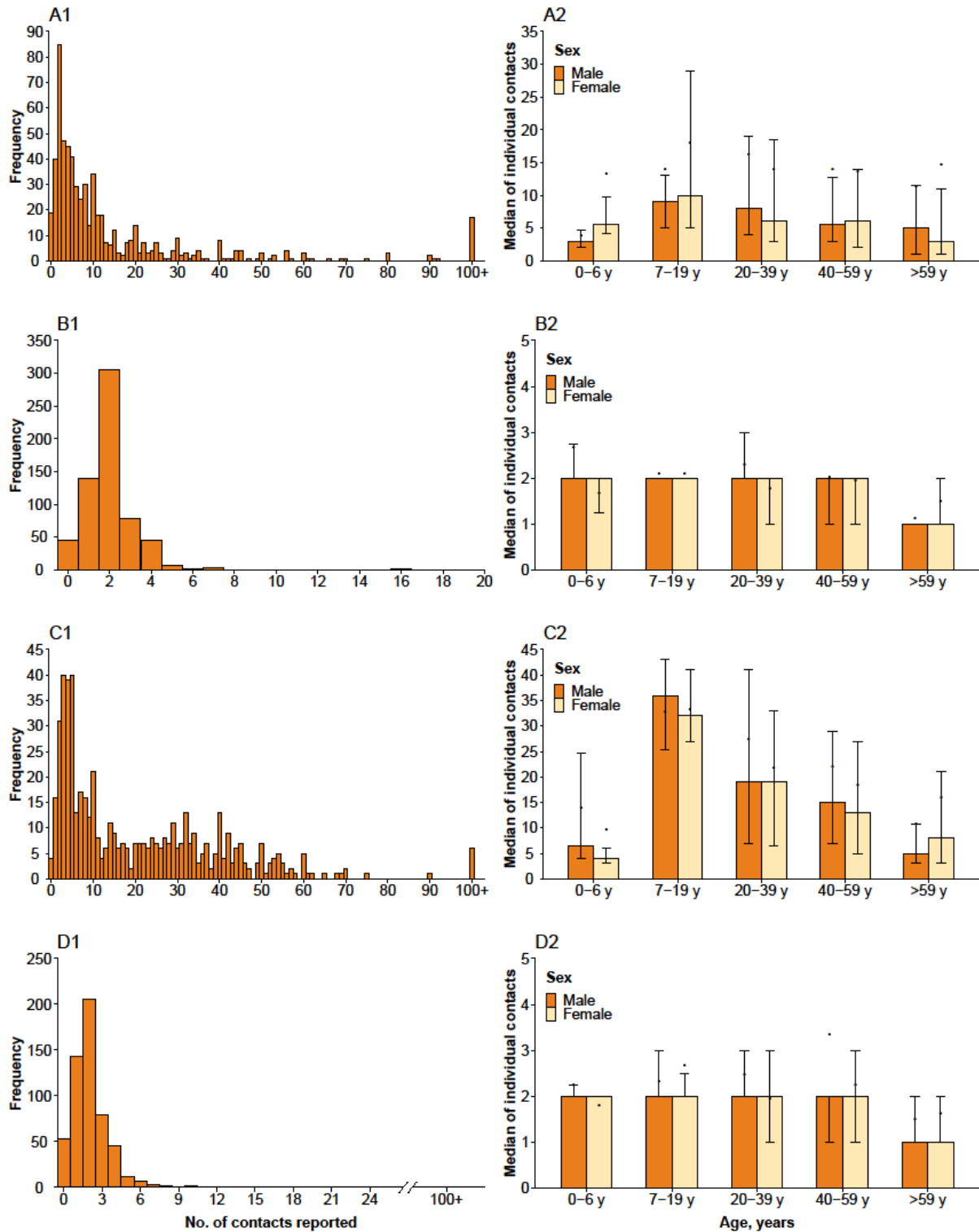


Figure S6. **A1** Distribution of contacts reported during regular days for Wuhan. **A2** Distribution of contacts reported by age group and sex during regular days for Wuhan. **B1** Same as A1, but for Wuhan during outbreak. **B2** Same as A2, but for Wuhan during outbreak. **C1** Same as A1, but for Shanghai. **C2** Same as A2, but for Shanghai. **D1** Same as B1, but for Shanghai. **D2** Same as B2, but for Shanghai. The error bars correspond to 25th and 75th percentiles, and the solid points correspond to the means. Number of contacts were censored by 100.

8. Physical contacts

We analyzed the contact diaries for the both locations and found that during the COVID-19 outbreak, survey participants reported on average 1.2 (95% CI 1.1-1.3) and 1.3 (95% CI 1.2-1.4) physical contacts in Wuhan and Shanghai, respectively. In Wuhan, the number of physical contacts dropped 2.8-fold during the outbreak ($P < 0.001$). No comparable data on physical contacts was available for Shanghai. Tab. S5 provides details on the number of physical contacts by characteristics of study participant, city and time period.

Table S5. Number of physical contacts for Wuhan and Shanghai.

Characteristics	Wuhan				Difference	Shanghai		Difference [#]
	Regular day		COVID-19 Outbreak			COVID-19 Outbreak		
	N (%) ^a	Mean (95% CI)	N ^a (%)	Mean (95% CI)		N (%)	Mean (95% CI)	
Overall	622 (100.0)	3.3 (2.7, 3.9)	627 (100.0)	1.2 (1.1, 1.3)	2.1 ^{***}	557 (100.0)	1.3 (1.2, 1.4)	0.1
Sex								
Male	299 (48.1)	2.7 (2.2, 3.3)	301 (48)	1.2 (1.1, 1.3)	1.6 ^{***}	286 (51.3)	1.3 (1.1, 1.5)	0.1
Female	323 (51.9)	3.8 (2.8, 4.8)	326 (52)	1.3 (1.2, 1.4)	2.5 ^{***}	271 (48.7)	1.4 (1.2, 1.5)	0.1
Age group								
0-6 y	12 (1.9)	2.9 (1.1, 4.8)	12 (1.9)	1.8 (1, 2.6)	1.1	14 (2.5)	1.8 (1.4, 2.2)	0
7-19 y	79 (12.7)	4.3 (3.2, 5.5)	79 (12.6)	1.3 (1.1, 1.5)	3 ^{***}	55 (9.9)	1.5 (0.7, 2.3)	0.2
20-39 y	254 (40.8)	4 (2.9, 5)	256 (40.8)	1.3 (1.2, 1.5)	2.6 ^{***}	254 (45.6)	1.3 (1.2, 1.5)	0
40-59 y	219 (35.2)	2.7 (1.7, 3.8)	220 (35.1)	1.2 (1, 1.3)	1.6 ^{**}	160 (28.7)	1.3 (1.2, 1.5)	0.2
>59 y	58 (9.3)	0.9 (0.4, 1.4)	60 (9.6)	0.9 (0.6, 1.2)	0.2	74 (13.3)	1 (0.8, 1.2)	0.1
Type of profession								
Pre-school	12 (1.9)	2.9 (1.1, 4.8)	12 (1.9)	1.8 (1, 2.6)	1.1	14 (2.5)	1.8 (1.4, 2.2)	0
Student	107 (17.2)	3.8 (2.9, 4.7)	107 (17.1)	1.3 (1.1, 1.5)	2.6 ^{***}	71 (12.7)	1.5 (0.8, 2.1)	0.2
Employed	389 (62.5)	3.4 (2.7, 4.1)	390 (62.2)	1.3 (1.2, 1.4)	2.2 ^{***}	354 (63.6)	1.4 (1.2, 1.5)	0.1
Unemployed	30 (4.8)	5.7 (0, 12.4)	31 (4.9)	1.5 (0.9, 2)	4.2	24 (4.3)	1.5 (0.9, 2.1)	0
Retired	84 (13.5)	1.2 (0.7, 1.8)	87 (13.9)	0.8 (0.6, 1)	0.5	94 (16.9)	1 (0.8, 1.2)	0.2
Household size								
1-2	118 (19)	1.4 (0.6, 2.2)	121 (19.3)	0.4 (0.3, 0.6)	1 ^{**}	199 (35.7)	0.5 (0.4, 0.6)	0.1
3-4	414 (66.6)	3.4 (2.8, 4.1)	415 (66.2)	1.3 (1.2, 1.4)	2.2 ^{***}	294 (52.8)	1.5 (1.4, 1.6)	0.2 ^{**}
>4	90 (14.5)	5.1 (2.6, 7.6)	91 (14.5)	2.1 (1.8, 2.5)	3.1 [*]	64 (11.5)	3 (2.2, 3.8)	0.9 [*]

^aCan differ from total sample size (n=636) as it also includes participants who had not recorded contacts during regular weekdays or during the COVID-19 outbreak. Note that reduced denominators indicate missing data. Percentages may not total 100 because of rounding.

*p<0.05, **p<0.01, ***p<0.001.

#Difference between Shanghai outbreak and Wuhan outbreak. We had no physical contact data during regular days for Shanghai.

9. Comparison of contact patterns between two locations

Compared with the participants in Wuhan, Shanghai residents recorded more contacts during regular days, while no significant difference was found during the COVID-19 outbreak (Tab. S6).

Table S6. Number of contacts during regular days and during outbreak.

Characteristics	Regular day					COVID-19 Outbreak				
	Shanghai		Wuhan		Difference	Shanghai		Wuhan		Difference
	N (%)	Mean (95% CI)	N ^a (%)	Mean (95% CI)		N (%)	Mean (95% CI)	N (%) ^a	Mean (95% CI)	
Overall	543	20.6 (19, 22.3)	624 (100.0)	14.6 (13, 16.3)	6***	557 (100.0)	2.3 (1.9, 2.7)	627 (100.0)	2 (1.9, 2.1)	0.3
Sex										
Male	264 (48.6)	21.3 (18.8, 23.8)	300 (48.1)	14.5 (12.2, 16.9)	6.7***	286 (51.3)	2.1 (1.8, 2.3)	301 (48)	1.8 (1.7, 2)	0.3
Female	279 (51.4)	20 (17.8, 22.2)	324 (51.9)	14.7 (12.4, 17)	5.3**	271 (48.7)	2.6 (1.8, 3.3)	326 (52)	2.1 (2, 2.3)	0.5
Age group										
0-6 y	51 (9.4)	11.5 (8.1, 14.9)	12 (1.9)	8.6 (0, 17.7)	2.9	14 (2.5)	1.9 (1.7, 2.2)	12 (1.9)	2.2 (1.5, 2.8)	-0.2
7-19 y	83 (15.3)	33 (29.2, 36.9)	79 (12.7)	16.2 (12.5, 19.8)	16.9***	55 (9.9)	2.6 (1.7, 3.4)	79 (12.6)	2.1 (2, 2.2)	0.5
20-39 y	132 (24.3)	24.6 (20.8, 28.5)	254 (40.7)	15.3 (12.6, 17.9)	9.4***	254 (45.6)	2.2 (2, 2.5)	256 (40.8)	2.1 (1.9, 2.2)	0.1
40-59 y	126 (23.2)	20.4 (17.2, 23.7)	221 (35.4)	13.8 (11, 16.6)	6.6**	160 (28.7)	2.8 (1.6, 4.1)	220 (35.1)	2 (1.8, 2.2)	0.8
>59 y	151 (27.8)	13.5 (10.9, 16.1)	58 (9.3)	13.9 (7.3, 20.5)	-0.4	74 (13.3)	1.6 (1.3, 1.8)	60 (9.6)	1.4 (1.2, 1.7)	0.1
Type of profession										
Pre-school	43 (7.9)	10 (6.4, 13.5)	12 (1.9)	8.6 (0, 17.7)	1.4	14 (2.5)	1.9 (1.7, 2.2)	12 (1.9)	2.2 (1.5, 2.8)	-0.2
Student	100 (18.5)	31.1 (27.7, 34.5)	107 (17.1)	14.6 (11.3, 18)	16.5***	71 (12.7)	2.5 (1.8, 3.1)	107 (17.1)	2.1 (2, 2.3)	0.3
Employed	236 (43.6)	23.9 (21.2, 26.6)	391 (62.7)	15.4 (13.3, 17.5)	8.6***	354 (63.6)	2.5 (2, 3.1)	390 (62.2)	2.1 (1.9, 2.2)	0.5
Unemployed	10 (1.8)	12.4 (0.8, 24)	30 (4.8)	14.1 (4.2, 24)	-1.7	24 (4.3)	1.8 (1.3, 2.4)	31 (4.9)	1.8 (1.3, 2.4)	0
Retired	152 (28.1)	12 (9.7, 14.3)	84 (13.5)	12.1 (7, 17.2)	-0.1	94 (16.9)	1.6 (1.3, 1.8)	87 (13.9)	1.5 (1.3, 1.7)	0.1
Household size										
1-2	166 (30.6)	15.6 (12.8, 18.4)	118 (18.9)	11.8 (7.8, 15.8)	3.8	199 (35.7)	1.1 (0.8, 1.3)	121 (19.3)	0.9 (0.6, 1.2)	0.2
3-4	306 (56.4)	21.8 (19.8, 23.9)	415 (66.5)	13.9 (12.1, 15.7)	7.9***	294 (52.8)	2.4 (2.3, 2.5)	415 (66.2)	2 (2, 2.1)	0.4***
>4	71 (13.1)	27 (21.3, 32.7)	91 (14.6)	21.5 (15.8, 27.1)	5.6	64 (11.5)	5.9 (2.8, 8.9)	91 (14.5)	3.2 (2.9, 3.4)	2.7

*Can differ from total sample size (n=636) as it also includes participants who had not recorded contacts during regular weekdays or during the COVID-19 outbreak. Note that reduced denominators indicate missing data. Percentages may not total 100 because of rounding.

*p<0.05, **p<0.01, ***p<0.001.

10. Regression model

We regressed the number of contacts on participant age and household size using multiple generalized additive model, separately for each location and time period (regular non-outbreak weekday, COVID-19 weekday). A log link was used, as the number of contacts was a good fit to a lognormal distribution. Penalized spline was used to explore potential nonlinear relationships between participant age (continuous variable) and number of contacts.

In the regression model, household size had significant contribution on the number of contacts, especially during the outbreak. Further, the number of contacts had a significant nonlinear association with participant age for regular weekdays. After adjusting the nonlinear association between the participant age and the number of contacts, participants in larger households had significantly greater number of contacts, especially during the outbreak (see Tab. S7 and Fig. S7).

Table S7. Generalized additive model regression coefficient.

Household size	Wuhan		Shanghai	
	Regular day	COVID-19 Outbreak	Regular day	COVID-19 Outbreak
	Exp (beta) and 95% CI	Exp (beta) and 95% CI	Exp (beta) and 95% CI	Exp (beta) and 95% CI
Intercept	14.4 (12.4, 16.8)	1.7 (1.7, 1.8)	17 (14.3, 20.3)	1.9 (1.5, 2.5)
1-2	Ref	Ref	Ref	Ref
3-4	1 (0.8, 1.3)	1.5 (1.4, 1.5)***	1.1 (0.9, 1.3)	2.2 (1.6, 3)***
>4	1.7 (1.2, 2.4)**	2.1 (1.9, 2.3)***	1.7 (1.3, 2.1)***	2.3 (1.3, 3.9)**

*p<0.05, **p<0.01, ***p<0.001.

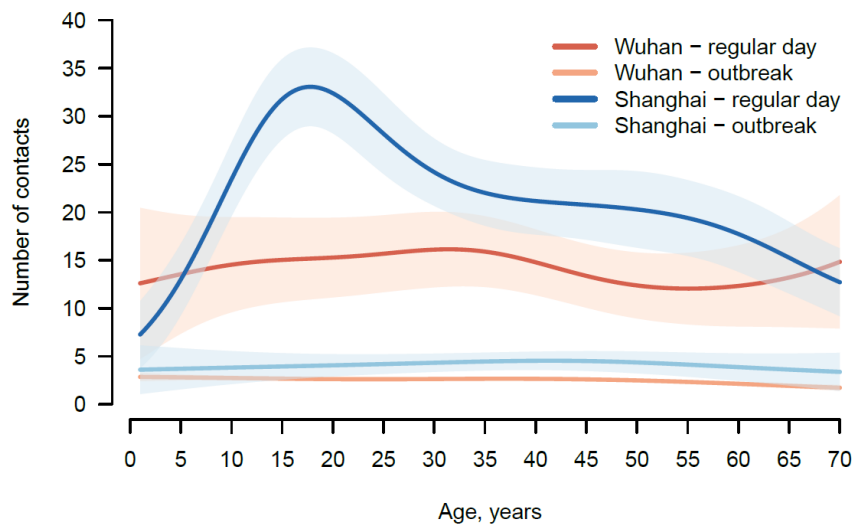


Figure S7. Estimated number of contacts in regression models assuming the household size is 3~4. 95% confidence intervals are denoted by a shaded region.

11. Bivariate smoothing of contact matrix

The bivariate smoothing approach was used to further estimation of the contact matrix, relying on the same methodology used in our previous contact study(5). The basis was a tensor-product spline ensuring flexibility when modeling the average number of contacts as a function of the responder's and contact's age over 1-year band. The average number of contacts between person aged i with person aged j was modeled using a two-dimensional continuous function applied to the age of participants and respondents, via a generalized additive model (GAM). We used the *gam* function from the *mgcv* package in R.

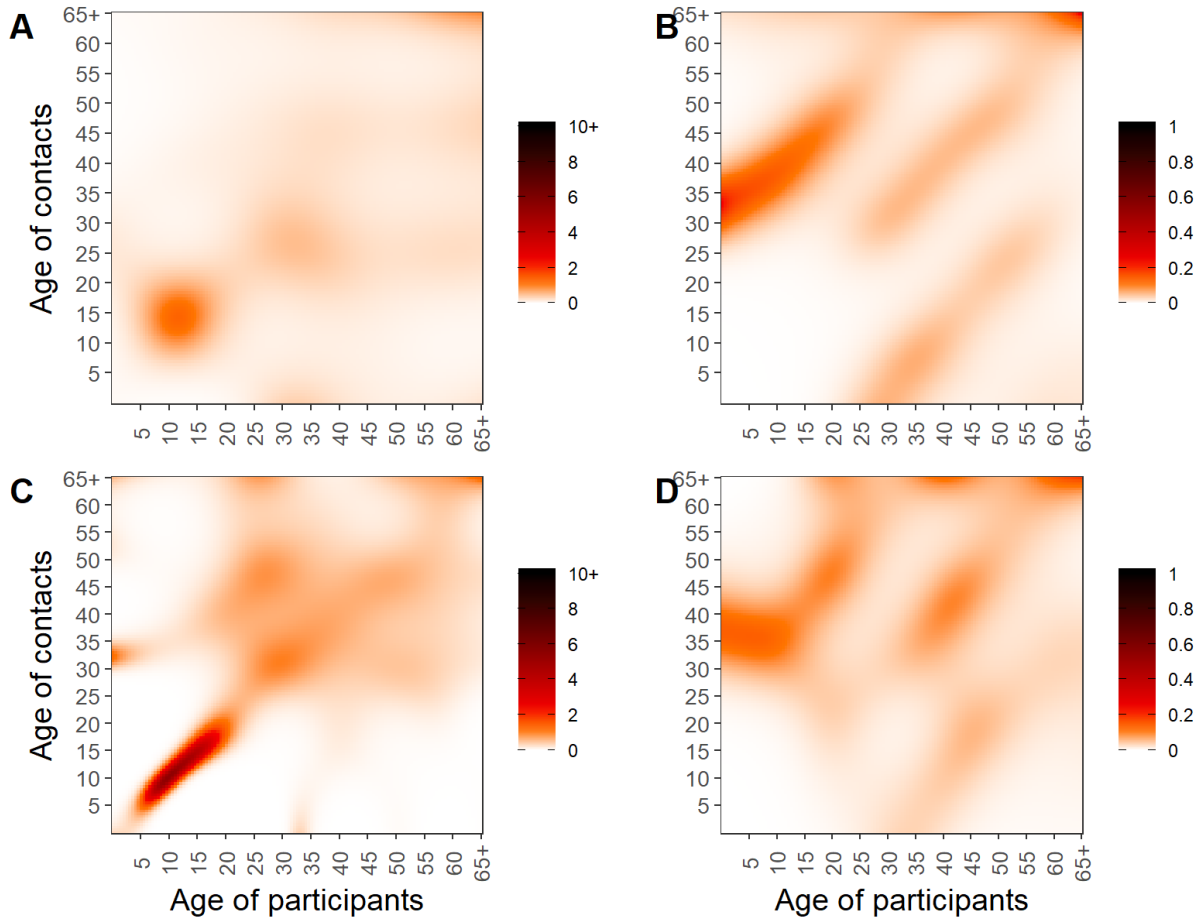


Figure S8. *A* Smoothed regular day contact matrix for Wuhan. *B* Smoothed outbreak contact matrix for Wuhan. *C* Same as A, but for Shanghai. *D* Same as B, but for Shanghai.

12. Analysis of contact setting and relationship during the COVID-19 outbreak

We analyzed the recorded contacts by social setting where the interaction took place (e.g., home, workplace, hospital) and by relationship between the participant and his/her contacts (e.g., member of the same household, work colleague). We found that, in both cities, the vast majority of contacts during the outbreak period occurred at home and with household members (Fig. S9).

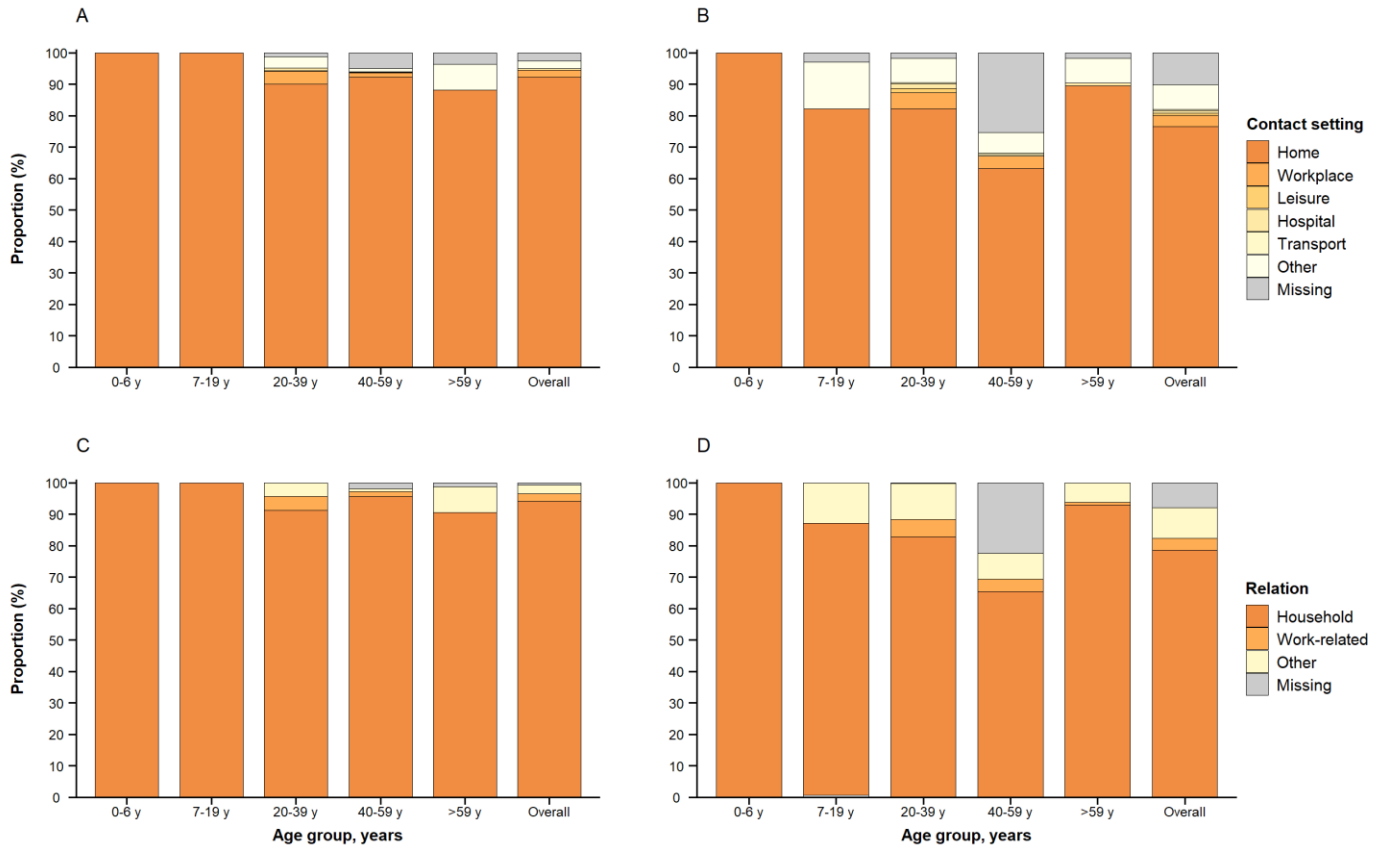


Figure S9. *A* Frequency of settings where contacts took place during the COVID-19 outbreak in Wuhan. *B* Same as A, but in Shanghai. *C* Frequency of relationships between contacts during the COVID-19 outbreak in Wuhan. *D* Same as C, but in Shanghai.

13. Comparison between the COVID-19 outbreak contact matrices and the within-household contact matrices

We found that the contact matrices during the COVID-19 outbreak are nearly identical to the within-household contact matrix both in Wuhan and Shanghai (Fig. S10A and S10C). We calculated the Pearson's coefficient between these two matrices and found highly significant correlations (0.99 for Wuhan and 0.95 for Shanghai, Fig. S10B and S10D).

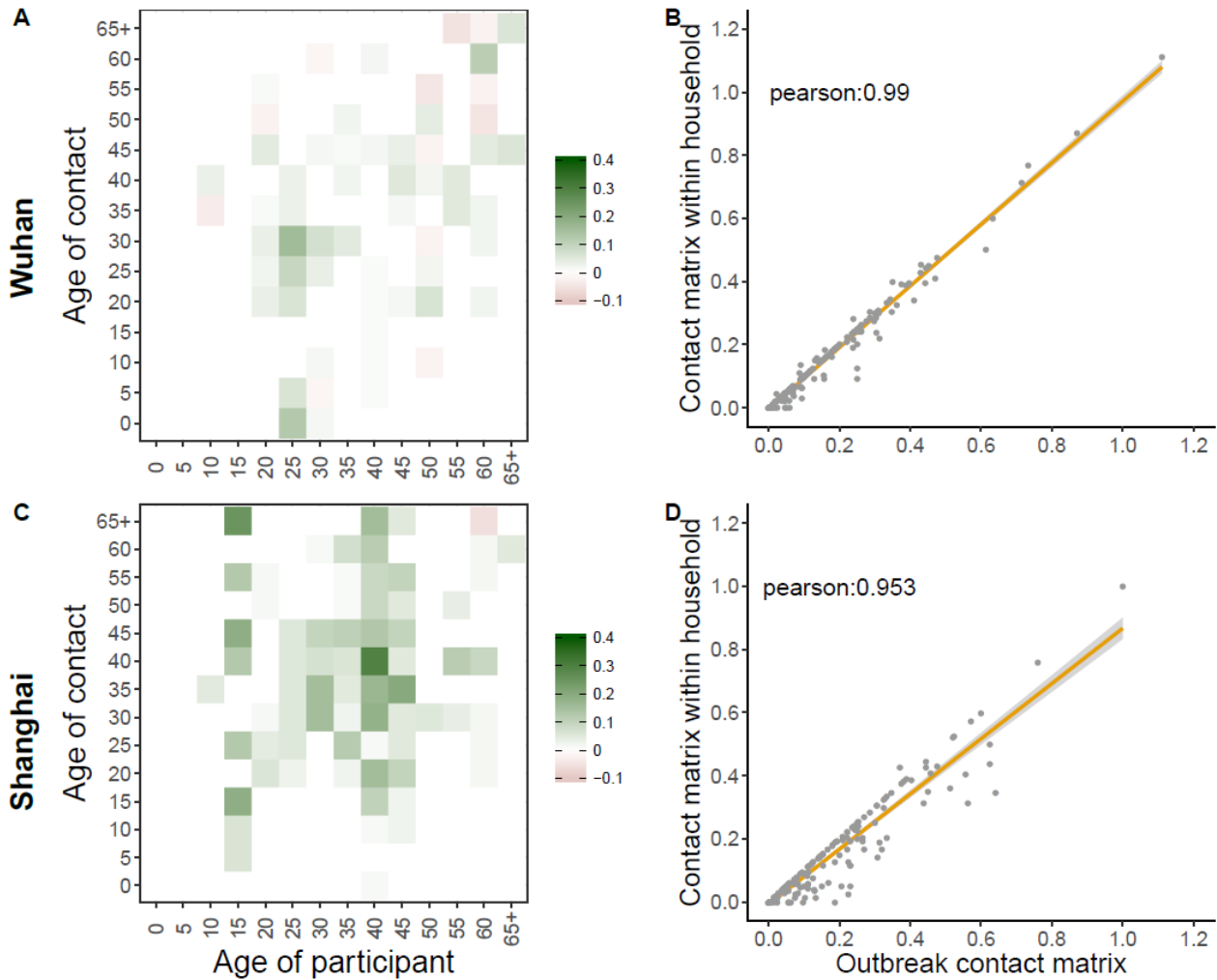


Figure S10. **A** Difference between the outbreak contact matrix and the within-household contact matrix for Wuhan. **B** Correlation between the elements of the outbreak contact matrix and the within-household contact matrix for Wuhan. The panel also reports the value of the Pearson correlation coefficient. **C** and **D** Same as **A** and **B**, but for Shanghai.

14. Assortativity of contacts

In order to assess the degree of age assortativity of the estimated contact matrices, we calculated the *q-index*, a measure representing departures from proportionate mixing, ranging from zero (proportionate) to one (fully assortative)(7). In particular,

$$q\text{-index} = \widehat{\lambda}_2 / \widehat{\lambda}_1$$

where $(\widehat{\lambda}_1, \dots, \widehat{\lambda}_M)$ is the vector of the absolute values of the real part of the eigenvalues of the contact matrix, ordered from the largest (i.e., the dominant eigenvalue) to the smallest.

We found that in Wuhan, age-mixing patterns were slightly more assortative (i.e., contacts mostly with individuals in the same age group) for regular days (q-index=0.59) than those during the COVID-19 outbreak (q-index=0.46). During the outbreak, participants aged 0-14 years reported no contacts with individuals in the same age group (see Fig. S11). In Shanghai, a much larger drop in assortativity was found during COVID-19. On a regular weekday, the q-index was 0.78, while it dropped to 0.39 during the outbreak. For participants aged 0-19 years, no contacts were recorded with individuals of the same age group. Both in Wuhan and Shanghai we observed an increase in contacts with individuals of the same age group among the elderly (Fig. S11).

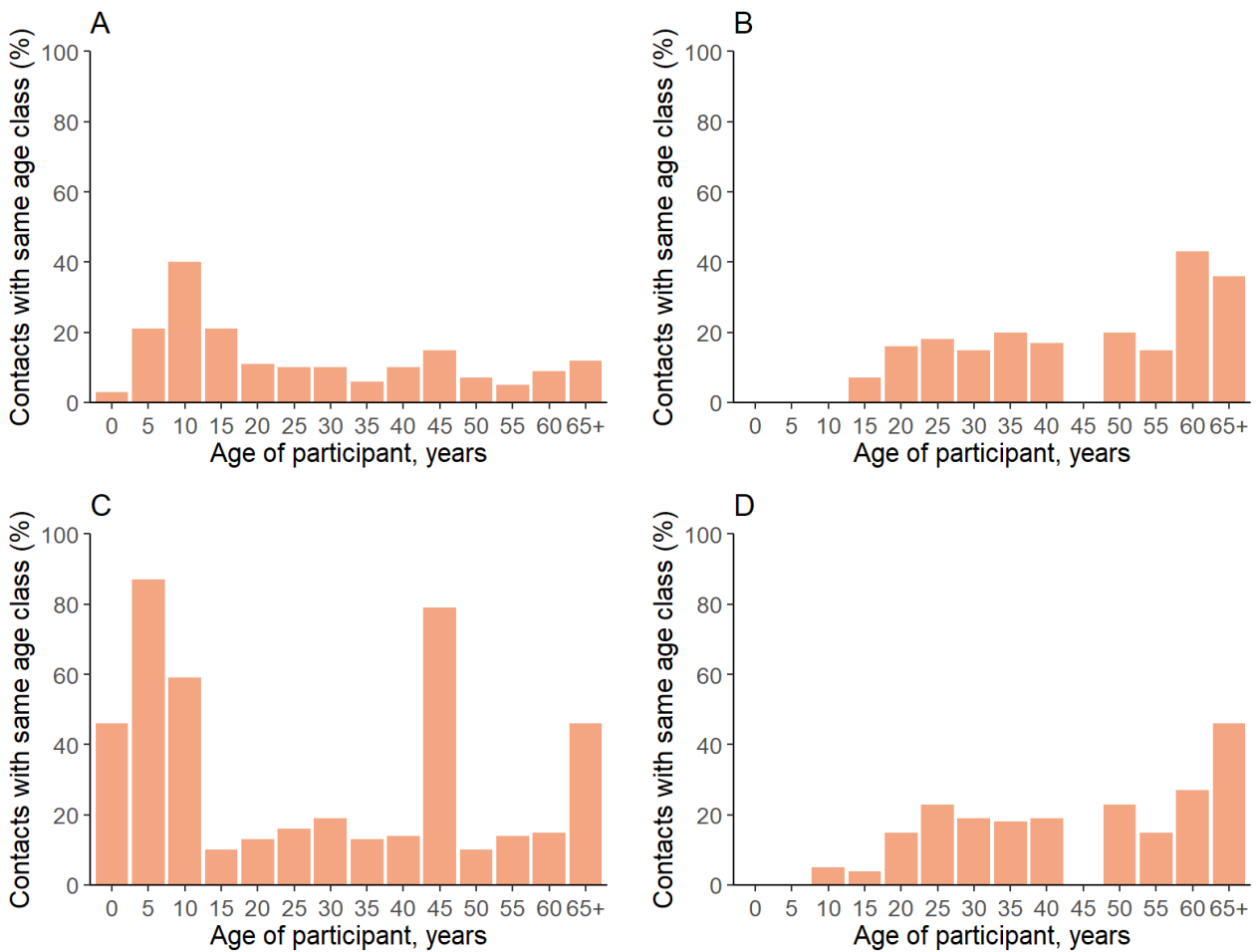


Figure S11. *A* The proportion of contacts with the same age class during regular weekdays in Wuhan. *B* Same as A, but during the COVID-19 outbreak. *C* Same as A, but in Shanghai. *D* Same as B, but in Shanghai.

15. Contact matrix data

The entries of the contact matrices for regular weekdays and for the COVID-19 outbreak in Wuhan and Shanghai are provided in Tab. S8-S11.

Table S8. Original contact matrix (equal 5-year age bands) of reported contacts for participants in Wuhan during regular weekdays, consisting of the average number of contact persons recorded per day per survey participant.

		Age of contact													
		0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65+
Age of participant	0-4	0.11	0.33	0.44	0.56	0.89	0.33	0.56	0.11	0.00	0.00	0.00	0.00	0.11	0.33
	5-9	1.77	2.39	2.26	5.94	0.61	0.58	0.61	0.55	0.19	0.23	0.29	0.16	0.16	0.19
	10-14	0.07	3.77	4.23	8.63	0.63	0.73	0.43	0.33	0.47	0.60	0.20	0.33	0.03	0.17
	15-19	0.00	1.33	1.62	4.43	0.57	0.43	0.43	0.24	0.62	0.48	0.24	0.29	0.24	0.14
	20-24	0.33	0.37	0.16	0.83	2.64	1.66	1.67	1.36	0.80	0.94	0.59	0.65	0.17	0.42
	25-29	1.31	0.69	0.38	0.97	2.97	1.59	1.56	1.38	0.72	0.94	0.41	0.47	0.19	0.44
	30-34	1.34	1.25	0.34	1.07	2.66	1.79	1.59	1.27	0.82	1.14	0.75	0.63	0.30	0.50
	35-39	0.80	0.94	0.51	1.30	3.10	1.90	1.81	1.70	1.29	1.39	0.79	0.81	0.48	0.80
	40-44	0.83	0.63	0.34	0.83	2.35	1.17	1.20	1.21	0.80	1.30	0.74	0.58	0.76	1.57
	45-49	0.40	0.81	0.40	1.33	1.34	0.72	0.88	0.84	1.00	1.14	0.91	0.78	0.45	0.83
	50-54	0.37	0.57	0.24	0.76	1.24	0.93	0.76	0.59	0.87	1.15	0.85	0.63	1.00	2.04
	55-59	0.55	0.70	0.25	1.10	1.90	1.00	1.00	1.35	1.20	0.65	1.00	0.85	1.60	3.95
	60-64	0.36	0.23	0.14	0.39	1.27	0.73	0.75	0.59	0.98	1.70	0.86	0.73	1.16	2.68
	65+	1.00	0.65	0.29	0.82	1.94	1.41	1.24	0.65	1.06	1.12	0.71	1.18	0.94	1.82

Table S9. Original contact matrix (equal 5-year age bands) of reported contacts for participants in Wuhan during the COVID-19 outbreak, consisting of the average number of contact persons recorded per day per survey participant.

		Age of contact													
		0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65+
Age of participant	0-4	0.00	0.11	0.00	0.00	0.00	0.00	1.11	0.44	0.22	0.00	0.00	0.00	0.22	0.11
	5-9	0.00	0.00	0.00	0.00	0.06	0.06	0.45	0.87	0.19	0.10	0.06	0.10	0.26	0.06
	10-14	0.00	0.00	0.00	0.03	0.00	0.00	0.03	0.73	0.63	0.33	0.17	0.03	0.00	0.07
	15-19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.48	0.71	0.14	0.00	0.05	0.19
	20-24	0.03	0.02	0.01	0.05	0.13	0.05	0.06	0.01	0.19	0.44	0.43	0.22	0.10	0.09
	25-29	0.25	0.16	0.03	0.03	0.09	0.31	0.25	0.09	0.09	0.03	0.34	0.19	0.09	0.03
	30-34	0.30	0.38	0.18	0.00	0.00	0.07	0.41	0.25	0.09	0.02	0.05	0.13	0.29	0.16
	35-39	0.14	0.31	0.29	0.06	0.00	0.01	0.24	0.31	0.30	0.04	0.02	0.04	0.18	0.17
	40-44	0.04	0.07	0.31	0.25	0.08	0.01	0.02	0.10	0.39	0.26	0.07	0.01	0.05	0.26
	45-49	0.00	0.07	0.02	0.24	0.26	0.16	0.02	0.07	0.16	0.36	0.28	0.10	0.02	0.40
	50-54	0.04	0.00	0.02	0.02	0.30	0.24	0.09	0.04	0.04	0.13	0.35	0.24	0.04	0.17
	55-59	0.25	0.00	0.05	0.00	0.10	0.20	0.15	0.05	0.25	0.00	0.15	0.30	0.10	0.35
	60-64	0.05	0.09	0.00	0.00	0.07	0.00	0.09	0.09	0.00	0.05	0.09	0.14	0.61	0.16
	65+	0.00	0.06	0.06	0.00	0.00	0.00	0.12	0.12	0.06	0.06	0.06	0.06	0.24	0.47

Table S10. Original contact matrix (equal 5-year age bands) of reported contacts for participants in Shanghai during regular weekdays, consisting of the average number of contact persons recorded per day per survey participant.

		Age of contact													
		0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65+
Age of participant	0-4	4.02	0.20	0.02	0.02	0.00	0.54	1.34	0.49	0.17	0.10	0.20	0.46	0.61	0.63
	5-9	0.04	17.76	0.52	0.00	0.04	0.32	1.04	1.24	0.28	0.16	0.04	0.28	0.44	0.32
	10-14	0.00	0.46	29.11	0.71	0.06	0.06	0.23	0.91	0.63	0.57	0.14	0.03	0.11	0.31
	15-19	0.00	0.06	0.39	21.67	1.00	1.18	1.88	3.06	1.94	1.94	1.21	0.88	0.30	0.91
	20-24	0.09	0.00	0.09	0.09	2.50	2.95	2.82	3.32	2.55	3.59	2.00	1.68	1.05	1.23
	25-29	0.09	0.06	0.06	0.24	0.76	2.67	2.64	3.09	2.06	2.48	1.73	1.61	1.09	1.79
	30-34	0.37	0.50	0.08	0.55	1.89	3.66	5.26	5.66	3.47	4.97	2.53	2.21	0.84	1.03
	35-39	0.15	0.28	0.36	0.15	0.87	1.74	2.54	3.54	2.67	2.62	1.00	1.15	0.77	0.59
	40-44	0.06	0.06	0.41	0.47	0.91	1.94	2.78	4.13	2.59	2.91	1.59	1.13	0.22	0.66
	45-49	0.05	0.13	0.24	0.29	1.26	1.68	2.45	2.84	2.55	2.66	2.37	1.05	0.63	1.37
	50-54	0.13	0.04	0.17	0.08	1.42	2.08	1.38	3.33	2.08	3.42	2.38	1.71	1.71	2.79
	55-59	0.09	0.06	0.00	0.13	0.91	1.22	1.97	1.97	1.34	2.09	1.38	2.59	1.25	2.94
	60-64	0.05	0.03	0.03	0.08	0.27	0.78	1.08	1.46	1.16	1.35	1.32	1.24	2.00	2.92
	65+	0.04	0.15	0.04	0.04	0.17	0.26	0.32	0.66	0.84	0.70	0.87	0.93	1.62	5.62

Table S11. Original contact matrix (equal 5-year age bands) of reported contacts for participants in Shanghai during the COVID-19 outbreak, consisting of the average number of contact persons recorded per day per survey participant.

		Age of contact													
		0-4	5-9	10-14	15-19	20-24	25-29	30-34	35-39	40-44	45-49	50-54	55-59	60-64	65+
Age of participant	0-4	0.00	0.00	0.00	0.00	0.00	0.29	0.57	1.00	0.14	0.00	0.14	0.00	0.00	0.00
	5-9	0.04	0.00	0.00	0.00	0.00	0.24	0.52	0.76	0.12	0.08	0.00	0.00	0.00	0.00
	10-14	0.00	0.00	0.00	0.00	0.14	0.05	0.38	0.48	0.33	0.52	0.10	0.00	0.00	0.10
	15-19	0.13	0.06	0.19	0.19	0.25	0.44	0.13	0.19	0.63	0.63	0.38	0.31	0.00	0.56
	20-24	0.01	0.01	0.06	0.04	0.07	0.09	0.04	0.09	0.25	0.33	0.40	0.25	0.12	0.18
	25-29	0.06	0.06	0.00	0.03	0.08	0.22	0.08	0.11	0.06	0.11	0.31	0.31	0.03	0.06
	30-34	0.18	0.21	0.04	0.01	0.01	0.14	0.56	0.32	0.11	0.10	0.11	0.15	0.21	0.24
	35-39	0.14	0.24	0.19	0.07	0.02	0.13	0.11	0.46	0.27	0.17	0.02	0.02	0.27	0.33
	40-44	0.10	0.19	0.24	0.27	0.21	0.01	0.23	0.31	0.64	0.33	0.13	0.10	0.23	0.51
	45-49	0.00	0.00	0.25	0.33	0.23	0.13	0.08	0.23	0.20	0.45	0.30	0.15	0.00	0.10
	50-54	0.00	0.06	0.06	0.06	0.22	0.39	0.06	0.06	0.00	0.11	0.44	0.17	0.22	0.11
	55-59	0.04	0.04	0.00	0.00	0.15	0.08	0.23	0.00	0.23	0.08	0.15	0.27	0.35	0.15
	60-64	0.02	0.06	0.02	0.02	0.06	0.07	0.22	0.11	0.13	0.00	0.02	0.11	0.44	0.37
	65+	0.00	0.05	0.00	0.05	0.00	0.05	0.05	0.15	0.05	0.00	0.00	0.05	0.25	0.60

16. Analysis of contact tracing data in Hunan Province to estimate the age profile of susceptibility and infectivity

The analysis of susceptibility to infection by age and the probability of developing symptoms by age is based on the analysis of contact tracing data in Hunan province, using a line list of patient-level information collected by the Hunan CDC.

Case definitions

A suspected COVID-19 case was defined as a person with pneumonia who fulfilled the following clinical criteria (fever; respiratory symptoms; radiographic evidence of COVID-2019; low or normal white-cell count and low lymphocyte count in early onset) and within 14 days preceding symptom onset, had the following: 1) a travel history to or resided in epidemic regions (e.g., Hubei Province including Wuhan city or other communities with laboratory-confirmed cases); or 2) was in close contact with a laboratory-confirmed case.

A confirmed case was defined as an individual who met the criteria for a suspected case and was diagnosed with SARS-CoV2 based on positive viral nucleic acid test results of throat swab samples.

An asymptomatic infected individual was defined as an individual who was diagnosed through positive viral nucleic acid test, but had no COVID-19 symptoms (e.g., no fever, no dry cough). Asymptomatic cases were generally discovered through contact tracing of index cases.

The sum of symptomatic cases and asymptomatic individuals identified through contact tracing is hereafter referred to as the number of infections.

Data collection and contact tracing

On January 16, 2020, Hunan CDC identified the first case of 2019 novel coronavirus. Since then, Hunan CDC actively initiated field investigations to monitor the contacts of identified cases. Contacts were followed for 14 days after the last known exposure.

Contacts of COVID-19 cases were divided into close and general contacts. Close contacts were defined as: 1) individuals who had been within 1 meter of confirmed and suspected cases in the two days before the onset of illness of their suspected symptomatic infector and thereafter, AND did not take effective precautions during their contacts; OR 2) individuals who had been within 1 meter of confirmed and suspected cases in the two days before the sample collection of their suspected asymptomatic infector and thereafter, AND did not take effective precautions during their contacts.

Close contacts included 1) household members living with a case; 2) relatives who had been in close contact with a case; 3) healthcare workers who diagnosed, treated, or nursed a case; 4) other patients and caregivers in the same ward as a case; 5) friends, coworkers, or classmates who studied, worked, or had been in close contact with a case; 6) staff who were in contact with a case in public places; 7) persons who took the same vehicle and were in close contact with a case.

General contacts included those who had been exposed to the case during work, study, or public transportation, but did not meet the criteria for close contacts.

All close contacts were tested for SARS-CoV2 according to the official guidelines of Hunan province. During the study period, general contacts were not tested and were thus excluded from the analysis.

Statistical analysis

We analyzed the official line list of confirmed cases as well as their close contacts identified by the Hunan CDC between January 16, 2020 and March 1, 2020. A total of 91 clusters for confirmed cases were identified by contact tracing investigations. Among them, we selected 57 clusters where the information about the age of contacts was available for at least 50% of the individuals. A total of 2,778 contacts in 57 clusters were analyzed (Tab. S12). For 474 contacts in the 57 clusters the age information was missing and thus they were excluded from the analysis of relative susceptibility to infection and risk of developing symptoms by age.

We categorized contacts in 3 age groups (0-14 years, 15-64 years, and 65+ years). For each age group we calculated the total number of symptomatic cases, infections (including both symptomatic and asymptomatic individuals), and contacts. The index case of each cluster was excluded from the calculations. For each age group, the secondary attack rate was calculated as the crude ratio between the number of secondary cases and the total number of contacts. The secondary infection attack rate was calculated as the crude ratio between the number of secondary infections and the total number of contacts in each age group.

The age-specific susceptibility to infection, σ_a , was calculated as a relative risk ratio, using the 65+ years age group as a reference, following:

$$\sigma_a = \frac{i_a/k_a}{i_{40-64}/k_{40-64}}$$

where i_a is the number of infected individuals in age group a and k_a is the number of contacts in age group a .

Similarly, the age-specific relative risk of developing symptoms p_a was calculated as follows:

$$p_a = \frac{c_a/i_a}{c_{40-64}/i_{40-64}}$$

where c_a is the number of cases in age group a .

The 95% confidence interval for the relative susceptibility to infection was estimated using normal approximation and calculating the standard deviation sd as follows:

$$sd = \sqrt{\frac{1}{i_a} + \frac{1}{i_{40-64}} + \frac{1}{k_a} + \frac{1}{k_{40-64}}}$$

The same procedure was used for the relative risk of developing symptoms by age.

Presented p-values are calculated a chi-square test of independence by using R package “epitools”.

Results

In Tab. S12, we report the values used in this analysis and the results, including the estimated secondary attack rate and secondary infection attack rate.

Table S12. Characteristics of the 57 clusters in Hunan and estimates of the age-specific relative risk of infection and of developing symptoms by age. The age group 65+ years was chosen as reference.

	Age group (years)			Total (non-missing)	Missing
	0-14	15-64	≥65		
Number of secondary cases	5	89	15	109	11
Number of secondary infections	8	108	17	133	13
Number of contacts	305	2,210	263	2,778	474
Secondary symptomatic attack rate (%)	1.6	4.0	5.7	3.9	2.3
Secondary infection attack rate (%)	2.6	4.9	6.5	4.8	2.7
Relative susceptibility to infection by age (95%CI)	0.41 (0.18-0.93)	0.76 (0.46-1.24)	1	-	-
Relative susceptibility to infection by age (p-value)	0.026	0.270	-	-	-
Relative risk of developing symptoms by age (95%CI)	0.71 (0.40-1.25)	0.93 (0.77-1.13)	1	-	-
Relative risk of developing symptoms by age (p-value)	0.133	0.550	-	-	-

17. Modeling COVID-19 transmission

To simulate COVID-19 transmission dynamics using the information previously described on age-specific contact patterns, susceptibility, and risk of developing symptoms, we used a classic age-structured SIR model(8). Briefly, susceptible individuals can acquire the infection through contacts with infectious individuals. Infectious individuals, who are infected and able to transmit the infection, can either recover or die. Each of these compartments is divided into 14 5-year age groups (0–4, 5–9, ..., 60–64, 65+ years old). Susceptible individuals are exposed to an age-specific force of infection regulated by the average number of contacts per day that individuals of a given age group have with individuals of all age groups (i.e., the contact matrix – see Tab. S8-S11). We used the following set of differential equations to simulate this process:

$$\left\{ \begin{array}{l} \dot{S}_i = -\beta \sum_{j=1}^n M_{ij} \frac{I_j}{N_j} \sigma_i S_i \\ \dot{I}_i = \beta \sum_{j=1}^n M_{ij} \frac{I_j}{N_j} \sigma_i S_i - \gamma I_i \\ \dot{R}_i = \gamma I_i \end{array} \right.$$

where,

- i represents the age group;
- $n=14$ is the total number of age classes;
- S_i the number of susceptible individuals in age group i ;
- I_i the number of infectious individuals in age group i ;
- R_i the number of recovered individuals in age group i ;
- N_i the total number of individuals in age class i (i.e., $N_i = S_i + I_i + R_i$). The number of individuals in each age group was derived from official records(9).
- β is the transmission rate;
- γ is the recovery rate. In a SIR model, the recovery rate is equivalent to the inverse of the duration of the generation time(10). Therefore, we set $1/\gamma = 5.1$ days(11).
- M_{ij} is the average number of contacts between individuals in age group i with individuals in age group j . The matrix of elements M_{ij} represents the contact matrix for regular weekdays and the COVID-19 outbreak period, as estimated from our survey in Wuhan and Shanghai.
- σ_i is the susceptibility to infection of individuals in age group i .

The basic reproduction number R_0 is computed through the next-generation approach(12) and thus we have

$$R_0 = \frac{\beta}{\gamma} \rho(K)$$

where $\rho(K)$ is the spectral radius of matrix K and the elements of K are defined as $K_{ij} = \sigma_i M_{ij}$.

18. Limiting school contacts

To understand the possible effect of limiting school-related contacts, we rely on the contact diaries collected by Zhang et al. (5) in Shanghai over the period from December 2017 to May 2018. In particular, we estimated age-specific contact matrix for off-school days and vacation (hereafter referred as to “vacation” contact matrix) based on contact diaries relating to winter school holidays, public holidays (3 days for New Year, and 3 days for Labor Day) and weekends. We excluded contacts recorded during the Chinese New Year holidays, as contact patterns in that period are highly peculiar of that period only. In addition, we considered a second scenario based on the diaries for regular school/work days, but dropping all contacts that were made in the school setting. The resulting contact matrix (hereafter referred as to “Regular day, no contacts at school”) represents a very crude approximation of the possible change in contact patterns due to school closures. In fact, it does not account for the change in contact patterns of child-caring members in the families with school-age children and the possibly increasing number of contacts made by students in social settings other than school.

Those two additional contact matrices as well as those for regular days and for the outbreak situation are shown in Fig. S12. The matrices were used in the transmission model introduced in Sec. 17.

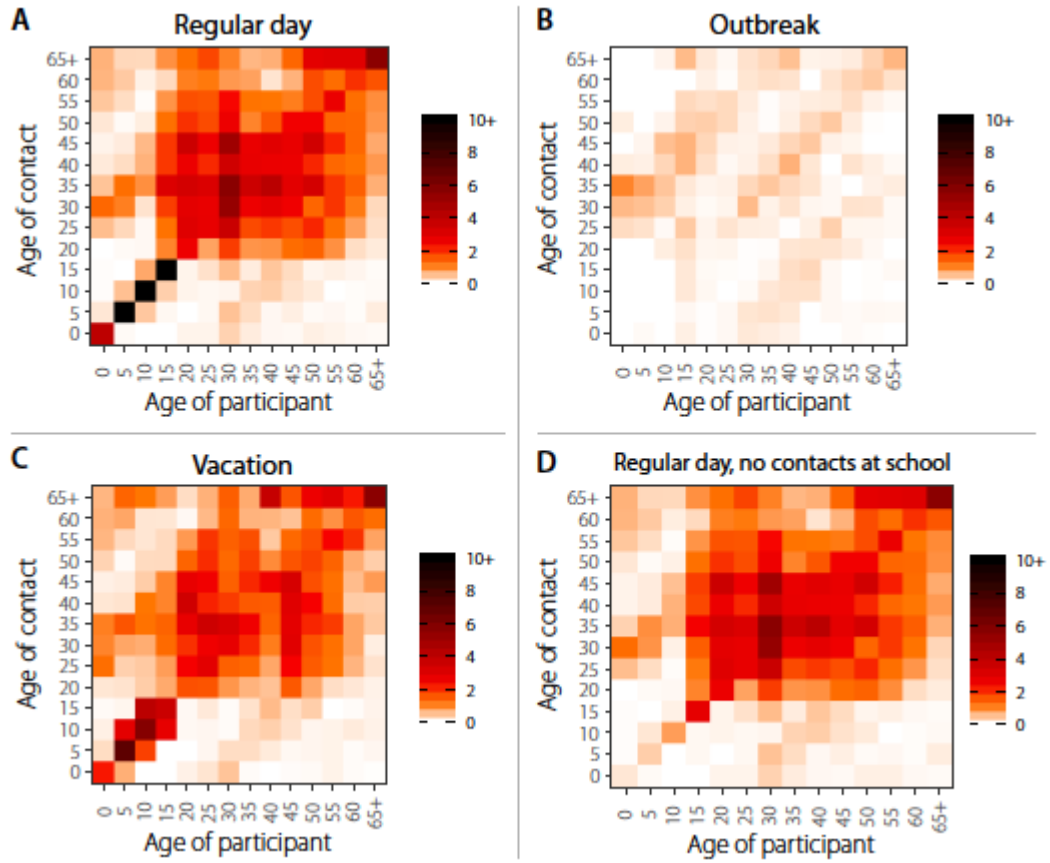


Figure S12. *A* Regular day contact matrix for Shanghai. *B* Outbreak contact matrix for Shanghai. *C* Contact matrix estimated in Shanghai during vacations(5) *D* Contact matrix estimated in Shanghai during regular days, suppressing all contacts occurring in school setting(5)

19. Sensitivity analysis assuming uniform susceptibility to infection by age

To understand to what extent the estimated susceptibility to infection by age affect the obtained modeling results, we simulated an alternative scenario where we assume that all age groups are equally susceptible to COVID-19 infection (i.e., $\sigma_i = 1$ for all i).

This assumption does not significantly affect our results (Fig. S13). For R_0 in the range 2.0-3.5, the implemented social distancing measures and human behavioral change are still estimated to lead the transmission well below the epidemic threshold both in Wuhan and Shanghai. Also the beneficial effect of limiting school contacts is clearly visible with a slightly more marked reduction of transmission than in the scenario accounting age-specific susceptibility to infection.

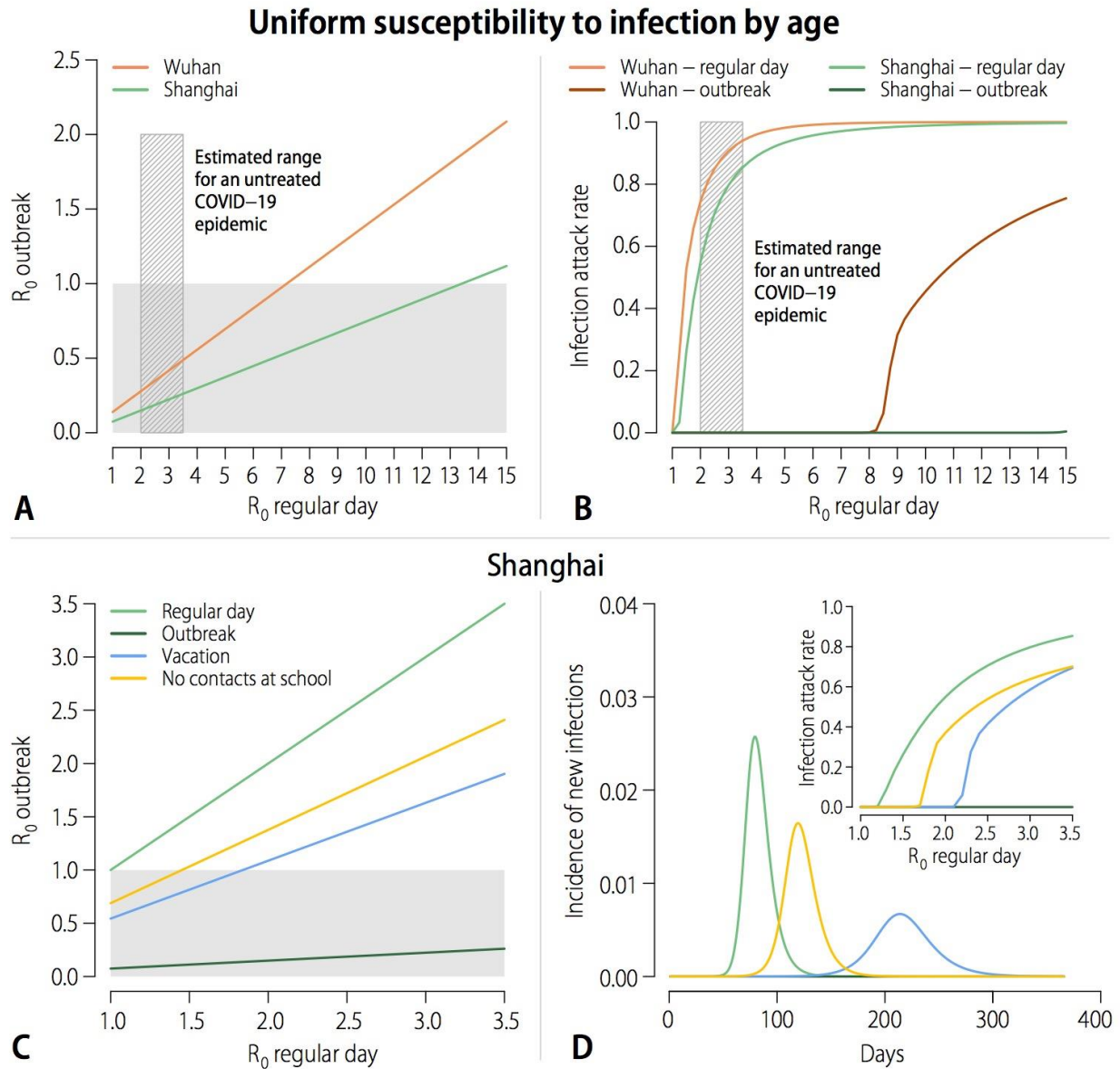


Figure S13. **A** Estimated R_0 with the outbreak contact matrix as a function of R_0 with the regular day contact matrix obtained by keeping fixed the transmission rate. The solid light grey rectangle represents the region where the R_0 in the outbreak situation is under the epidemic threshold. The shaded dashed black rectangle represents a plausible range of R_0 values in the early phase of the COVID-19 epidemic, as estimated in the literature. **B** Infection attack rate after 365 days since the first initial case as a function of R_0 computed by using the regular day contact matrix. The corresponding value of R_0 for the outbreak situation can be seen in panel A. **C** As A, but for Shanghai only and including two additional scenarios of contact patterns reduction: (i) during vacations (Vacation) and (ii) during regular days, suppressing all contacts occurring in school setting (No schools). **D** Daily incidence of new infections for the four scenarios presented in panel C (median). The inset shows the mean infection attack rate after 365 days since the first initial case.

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